Evaluation of Soil Survey Scale for Zone Development of Site-Specific Nitrogen Management

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ABSTRACT

Zone sampling for site-specific N application has been shown to be effective in North Dakota and other areas of the Great Plains. Printed and sometimes digitized soil surveys are presently available for most agricultural counties in the USA. Order 2 soil surveys generally have scales that range from 1:12 000 to 1:31 680. These surveys were developed for general planning purposes. There is interest in using Order 2 soil surveys as a basis for delineating N management zone patterns, especially where the soil-mapping units have been digitized. This study was conducted to evaluate soil survey scales at the Order 1 (scale >1:15 840) and Order 2 level against grid- and topography-based zone sampling to determine whether soil surveys at these scales could be used to delineate N management zones for site-specific fertilizer application. Fields mapped at a finer scale (Order 1 survey) showed some similarity between mapping units and N management zones defined by topography. Order 2 soil-mapping units, which are the present mapping scale of most agricultural soil surveys, were often not similar to N management zones. Published Order 2 soil surveys should not be used to develop N management zones for site-specific agriculture unless the soil patterns are verified with other zone development tools of site-specific management. Alternatively, a major benefit of Order 1 soil surveys would be to reinforce or redefine apparent N management zones.

Spatial nutrient information must be collected to direct a variable-rate fertilizer application. Soil testing is a basis for fertilizer recommendations. Soil testing requires enormous amounts of background research to develop the relationship between soil test level and crop response (Peck and Soltanpour, 1990). Soil test results must then undergo considerable correlation and calibration to develop fertilizer recommendations (Dahnke and Olson, 1990). In areas of low rainfall (<64 cm yr^{-1}), soil testing is a recommended and common practice for N management (Hergert et al., 1997). There are questions regarding the adequacy of N recommendations and their modification based on variable yield goals with landscape position; nonetheless, N soil testing is the only currently accepted method of determining the N status of the soil in many parts of the USA (Dahnke and Olson, 1990).

For successful precision nutrient management, accurate maps of soil test levels are needed (Sawyer, 1994). The three types of maps used or developed in site-specific agriculture include condition, performance, and prescription maps (Pierce and Nowak, 1999). Condition maps are those that are measured, predicted, or both. Performance maps site-specifically record inputs and outputs in time. Prescription maps of fertilizer rates are usually derived from one or more condition maps, modified perhaps by performance maps. The four condition-map categories for nutrient management are (i) soil surveys, (ii) interpolation of a network of point samples (i.e., grid sampling), (iii) yield monitor data or remotely sensed images, and (iv) modeling to estimate spatial nutrient patterns.

Soil surveys are compendiums of soils in a region. Compendiums contain information on boundaries of soil series, types, associations, or complexes that are usually traced on aerial photographs of the region. Most soil surveys in the USA are designated second order (Order 2) and have scales at 1:12 000 to 1:31 680, with minimum size delineation of 0.6 to 4 ha (1.5–10 acres) (Soil Survey Division Staff, 1993). Order 2 surveys were developed for intensive agriculture requiring detailed soils information for general planning purposes. A first-order (Order 1) soil survey uses scales larger than 1:15 840, with minimum size delineation of <1 ha (2.5 acres). Order 1 surveys are needed for applications requiring very detailed soils information. Although there is overlap in the definition of the two orders of soil survey, it is most common in North Dakota to map Order 2 on a scale of 1:20 000, with minimum size delineation 1.25 ha (3.1 acres), while the Order 1 surveys have scales approximately 1:6600, with minimum size delineation of 0.4 ha (1 acre).

In both an Order 1 and Order 2 survey, the main type of soil entry is designated a consociation (Soil Survey Division Staff, 1993). Order 2 surveys generally contain more complexes and associations than Order 1. A consociation by definition is dominated by a single soil taxon (a unit designated reasonably true to the namesake soil series properties), with at least 50% of the area within the consociation boundary consisting of the dominant soil taxon. Less than 15% of the area consists of dissimilar soil series, or <25% if the soil series have similar properties. Complexes are soil groupings that cannot be mapped separately at 1:24 000, and associations are groupings that can be mapped separately at 1:24 000. However, the actual practice of delineation regarding how these entries are eventually mapped appears to be left to the survey crew or state survey team, with considerable latitude on what similar and dissimilar mean. In the Red River valley of North Dakota, for example, section after section are often recorded as an association as though they had similar properties for important attributes (Prochnow et al., 1985). For properties such as engineering and general farm productivity, these assumptions are probably correct. However, given similar soil-forming factors of time, vegetation, climate, and parent material common to all soils in an association, the differences in topography that result in separa-

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tion of soil-series members within the association may also influence other factors, especially nutrient availability.

The problems associated with consociations, associations, and complexes were addressed by Nordt et al. (1991). They found that dominating taxa within a soil-mapping unit were much less in area than expected and recommended instead that consociations be designated multitaxa units when mapped at the 1:20 000 level to emphasize the variability within many mapping units.

Despite the usefulness of Order 2 soil surveys to direct natural-resource management, general farm evaluation, and engineering properties (Mausbach et al., 1993), few studies have shown them useful in directing site-specific activities. Carr et al. (1991) suggested that soil series could be used to direct site-specific management as long as soil series were identified and mapped accurately. Steinwand et al. (1996) examined a 64-ha (158 acre) field in Iowa in a Clarion–Webster–Nicollet association and found that the 1:15 840 and 1:3305 scales were similar in terms of predicting crop yields within a 3-yr study. They concluded that soil survey mapping could be used to direct site-specific decisions. However, the expected corn (*Zea mays* L.) yields ranged only from 8 to 10 Mg ha^{-1} in more than 90% of the field area, whereas soil nutrient levels in a North Dakota field varied as much as 100-fold (Franzen et al., 1998). It might be expected that it is easier to predict yield in fields with less variability.

Kellogg (1961, p. 19) recognized the possible shortcomings of published Order 2 surveys when he stated that, "soil complexes are set up as mapping units where the individual areas of soil are too small and too irregular to be separated on the map. This means that they are too small for separate treatment in fields where soils are handled with machines." The machines of 1961 were, of course, capable of only single rates of input and not responsive to more detailed soils information. Mausbach et al. (1993) and Atherton et al. (1999) concluded that soil surveys, as published today, are not appropriate for site-specific applications.

Grid and zone sampling can provide information required for site-specific mapping. Grid sampling uses a sufficiently dense array of samples to reveal soil nutrient patterns following interpolation of areas in between the samples. Many recent studies have focused on grid soil sampling to direct site-specific nutrient application (Wollenhaupt et al., 1994; Franzen and Peck, 1995; Lamb et al., 1995; Ferguson et al., 1996; Gotway et al., 1996; Clay et al., 1997). However, sampling for available N in drier regions is prohibitively expensive, so other techniques have been explored. For example, custom soil samplers in the Red River valley of North Dakota typically charge \$45 per grid point to sample for NO_3–N. A 66-m grid would cost \$110 ha^{-1}, which would be more than the cost of fertilizer in most fields.

Zone sampling assumes that nutrient patterns are based on some logical reason and are often associated with an easy-to-measure attribute compared with intensive sampling. Recently, zone sampling using topographic criteria (Franzen and Peck, 1996; Franzen et al., 1998; Westfall et al., 1998) provided soil nutrient information that was highly correlated with dense grid sampling (<0.1 ha) using fewer soil samples than a commercial grid-sampling (0.4–1 ha) approach (Wollenhaupt et al., 1994; Franzen and Peck, 1995). Topography is one of the five soil-forming factors (Jenny, 1941) and is a basis for unit separation in soil survey mapping. In many fields, the other four soil forming factors—time, past vegetation, climate, and parent material—are often constant. Therefore, if the soil map units have adequate resolution, then a soil survey might be used as the basis for nutrient zone definition.

This study was conducted to evaluate soil survey scales at the Order 1 and Order 2 scale and to compare these maps with grid sampling and topography-based zone maps to determine their relative value in delineating N management zones to direct site-specific N application.

MATERIALS AND METHODS

Five sites in North Dakota were studied. Four sites were square, 16.0-ha fields located near Gardner, Colfax, Valley City, and Hunter, ND. The fifth site was a 31.6-ha field located near Mandan, ND (Table 1). The Gardner site was studied from 1994 through 1996. The site was split into a north 6.0-ha field and a south 10.0-ha field, with continuous alfalfa (*Medicago sativa* L.) on the north field and a rotation of spring wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and alfalfa, respectively, on the south field in 1994 through 1996. The Colfax site was studied from 1995 through 1998, with corn, spring wheat, corn, and soybean [*Glycine max* (L.) Merr.] grown during that time. The Hunter field was studied in 1997 and 1998, with spring wheat in 1997 and sugarbeet (*Beta vulgaris* L.) in 1998. The Valley City field was studied from 1994 through 1998, with a rotation of spring wheat, sunflower (*Helianthus annuus* L.), spring wheat, barley, and spring wheat, respectively. The Mandan site was divided into three fields. Each field was seeded to either winter wheat, spring wheat, or sunflower.

Soil samples taken to a 60-cm depth were obtained from all sites in a regular 33-m grid each fall following harvest. Each sample consisted of a composite of three to five cores taken from a 5-m radius of the center of the grid. At the Mandan site, the two west fields were sampled in a 45-m grid instead of the 33-m grid. All samples from each location were

Table 1. Location and general properties of study fields.

Site	Lat./Long.	Parent material	Mean annual temperature	Mean annual precipitation
			°C	mm
Gardner	47.12°N/96.98°W	Lacustrine	4.7	451
Hunter	47.10°N/97.03°W	Lacustrine	4.7	451
Colfax	46.38°N/96.89°W	Lacustrine	5.6	485
Valley City	46.87°N/97.90°W	Glacial till	3.9	467
Mandan	46.76°N/100.92°W	Thin loess over till	5.2	399

Table 2. Soil series descriptions of study fields.

Site	Series	Series classification
Gardner	Enloe	Argiaquic Argialbolls, fine, smectitic, frigid
	Fargo	Typic Epiaquerts, fine, smectitic, frigid
	Hegne	Typic Calciaquerts, fine, smectitic, frigid
Hunter	Bearden	Aeric Calciaquolls, fine-silty, mixed, superactive, frigid
	Glyndon	Aeric Calciaquolls, coarse-silty, mixed, superactive, frigid
	Grano	Typic Endoaquerts, fine, smectitic, frigid
	Lindaas	Typic Argiudolls, fine, smectitic, frigid
	Overly	Pachic Hapludolls, fine-silty, mixed, superactive, frigid
	Perella	Typic Endoaquolls, fine-silty, mixed, superactive, frigid
Colfax	Embden	Pachic Hapludolls, coarse-loamy, mixed, superactive, frigid
	Hamar	Typic Endoaquolls, sandy, mixed, frigid
	Hecla	Aquic Hapludolls, sandy, mixed, frigid
	Glyndon	Aeric Calciaquolls, coarse-silty, mixed, superactive, frigid
	Maddock-disturbed	Entic Hapludolls, sandy, mixed, frigid
	Tiffany	Typic Endoaquolls, coarse-loamy, mixed, superactive, frigid
	Wyndmere	Aeric Calciaquolls, coarse-loamy, mixed, superactive, frigid
Valley City	Barnes	Calcic Hapludolls, fine-loamy, mixed, superactive, frigid
	Embden	Pachic Hapludolls, coarse-loamy, mixed, superactive, frigid
	Forman	Calcic Argiudolls, fine-loamy, mixed, superactive, frigid
	Hamerly	Aeric Calciaquolls, fine-loamy, mixed, superactive, frigid
	Lanona	Calcic Hapludolls, coarse-loamy, mixed, superactive, frigid
	Maddock	Entic Hapludolls, sandy, mixed, frigid
	Swenoda	Pachic Hapludolls, coarse-loamy, mixed, superactive, frigid
	Svea	Pachic Hapludolls, fine-loamy, mixed, superactive, frigid
	Tonka	Argiaquic Argialbolls, fine, smectitic, frigid
Mandan	Arnegard	Pachic Haplustolls, fine-loamy, mixed, superactive, frigid
	Belfield	Glossic Natrustolls, fine, smectitic, frigid
	Daglum	Vertic Natrustolls, fine, smectitic, frigid
	Farland	Typic Argiustolls, fine-silty, mixed, superactive, frigid
	Grail	Vertic Argiustolls, fine, smectitic, frigid
	Grassna	Pachic Haplustolls, fine-silty, mixed, superactive, frigid
	Regent	Vertic Argiustolls, fine, smectitic, frigid
	Temvik	Typic Haplustolls, fine-silty, mixed, superactive, frigid
	Williams	Typic Argiustolls, fine-loamy, mixed, superactive, frigid
	Wilton	Pachic Haplustolls, fine-silty, mixed, superactive, frigid

analyzed for NO_3–N using colorimetric transnitration with salicylic acid (Vendrell and Zupancic, 1990).

Topography was determined at all sites using a laser-surveying device, recording relative elevation measurements in a 33-m grid. Topography zones were delineated by subjectively drawing boundaries between hilltops, slopes, and depressions.

Order 1 soil surveys (1:6600) were produced by Michael Sweeney (Registered Professional Soil Classifier, North Dakota, and Professor Emeritus, North Dakota State Univ., Fargo) at the Colfax, Hunter, and Gardner sites. The Order 1 soil survey (1:6600) of Valley City was conducted by Dr. David Hopkins (Registered Professional Soil Classifier, North Dakota, and Assistant Professor, North Dakota State Univ., Fargo), and the Order 1 soil survey (1:6600) at Mandan was conducted by Michael Ulmer (Registered Professional Soil Classifier, North Dakota, and Soil Data Quality Specialist, NRCS, Bismarck, ND). The published soil surveys (Order 2) in Colfax, Gardner, and Valley City were mapped at 1:20 000, with a minimum of 1-ha soil size delineation. The published Order 2 soil survey at Mandan was mapped at a scale of 1:16 000, with minimum soil size delineation of 0.8 ha. Soil mapping unit classifications are displayed in Table 2.

Comparisons between soil survey zones and the original NO_3–N values of the 33- or 45-m grids were made by giving all sampling locations within a soil survey unit a mean NO_3–N value from up to eight random original NO_3–N values for that area (Fig. 1). These mean values were then correlated with the original values for each 33-m sampling location. Comparisons between topography and the original 33-m grid values were made in a similar manner. Comparisons between a 66-m grid (approximately 2.5 samples per hectare) and the original 33-m grid were conducted by deleting all sample values not representing a 66-m grid and then giving the deleted locations the value that represented that area after interpolation using inverse distance squared interpolation with the mapping program Surfer 3.2 for Windows (Golden Software Co., Golden, CO). This procedure has been used by several previous studies (Franzen and Peck, 1995; Franzen et al., 1998; Gotway et al., 1996).

Nitrogen management zones were defined by either topography or soil survey boundaries. Eight sample values from each zone were averaged and used to represent each 33-m

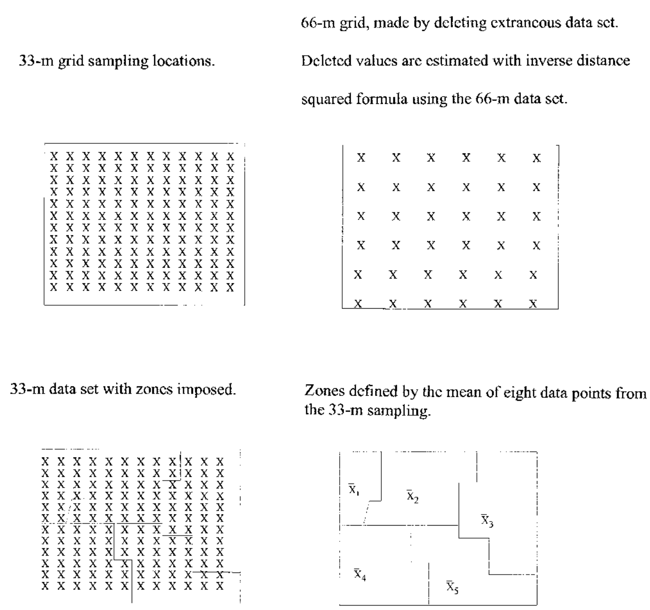


Fig. 1. Illustration of method of comparing grid density and zone sampling compared with the original 33-m sampling grid in a 12.5-ha test field.

Table 3. Descriptive statistics and geostatistics of NO_3–N levels. Geostatistical analysis was conducted on log-transformed data.

Site	Year	Mean	Range†	SD	Skewness	Kurtosis	Variogram model	Percent variation explained by model	Nugget	Sill	Range
		kg ha^{-1}						%			kg ha^{-1}
Gardner	1994	22.7	5–138	18.6	2.69	9.64	Linear	0.46	0.33	0.662	
	1995	23.5	8–104	16.2	2.63	8.14	Linear	0.72	0.20	0.333	
	1996	20.7	10–64	7.0	2.91	12.11	Linear	0.31	0.066	0.081	
Hunter	1997	54.6	26–108	15.6	0.64	0.48	Spherical	0.77	0.045	0.0897	0.0025
	1998	17.6	8–113	15.0	3.95	17.7	Linear	0.85	0.054	0.374	
Colfax	1995	54.1	7–150	35.4	0.70	−0.44	Spherical	0.86	0.111	0.557	0.07
	1996	44.0	12–183	33.6	2.10	4.38	Spherical	0.80	0.064	0.378	0.0013
	1997	30.0	11–190	24.3	2.96	13.42	Exponential	0.23	0.086	0.557	0.0009
	1998	59.3	6–414	48.6	3.69	20.31	Exponential	0.31	0.081	0.378	0.0009
Valley City	1994	50.6	4–554	54.4	5.82	49.5	Linear	0.64	0.55	0.772	
	1995	59.1	9–374	41.7	3.63	22.95	Spherical	0.54	0.094	0.392	0.0007
	1996	34.7	9–336	42.0	4.44	24.13	Linear	0.97	0.294	0.781	
	1997	64.8	20–201	32.3	1.27	2.50	Linear	0.86	0.206	0.273	
	1998	113.9	19–736	79.5	4.1	25.8	Linear	0.97	0.178	0.387	
Mandan	1995	18.6	9–110	9.7	5.28	7.76	Spherical	0.71	0.117	0.254	0.104
	1996	18.6	5–76	9.7	1.98	43.5	Spherical	0.79	0.025	0.14	0.087
	1997	35.9	4–198	36.8	1.38	1.86	Spherical	0.96	0.001	0.189	0.182
	1998	34.5	12–208	25.3	3.45	16.57	Exponential	0.93	0.110	0.302	0.0039

† Left range is normal data-set range. Right range is the geostatistical range from the variogram model.

grid location within the zone for correlation with the original 33-m sample values. This method of comparing grid density estimates and zones is also described in Franzen et al. (1998). Grid and zone estimates were compared with the 33-m grid values using simple correlation. A list of soil series encountered in the Order 1 or Order 2 surveys is shown in Table 1. Geostatistics were determined using GS+ 3.1 (Gamma Design Software, Plainwell, MI). All data sets were log-transformed before geostatistical analysis. Log transformation was necessary to satisfy a need for normalized data sets for geostatistical analysis. The log transformation did not completely normalize the data but improved its normality relative to the original data. Original data was used in all mapping and comparisons in other parts of this study.

RESULTS AND DISCUSSION

Descriptive statistics for each site-year are shown in Table 3. Skewness and kurtosis are displayed for the original data sets; however, a logarithmic transformation was imposed to increase the normality of each data set before geostatistical analysis. A comparison between maps made from the Order 1 soil surveys and the currently published soil surveys appears in Figures 2 through 6. As expected, the Order 1 surveys had more detail than the Order 2, and the series were different in the two maps. Generally, the soil series from the Order 1 survey designated for the field differs from the published series.

At the Gardner site (Fig. 2), the published Order 2 survey (Prochnow et al., 1985) identified only the Fargo–Hegne complex. The Order 1 survey separated these soils as well as several others. Differences between the maps may have resulted from the scale required for mapping the two different surveys and the time difference in delineating these features in the field to achieve the goals of each kind of survey. Certainly, the Order 2 survey is correct in its general land-use assessment of the field in suggesting that it could raise high yields of corn or sugarbeet and that the characteristics of the soil would make it limiting in the installation of drainage tile; however, it is not detailed enough to help manage within-field problems, such as directing soil sampling for variable-rate fertilizer application. The Order 1 survey helps direct the reader to similar general land assessment as the Order 2 map, but it also provides within-field delineation regarding areas that might be more homogenous in N availability. A comparison between the Order 1 and Order 2 soil surveys suggests that NO_3–N levels were higher in the Hegne than the other soils.

Nitrogen management zones based on the Order 1 soil survey at Gardner were significantly correlated with the 33-m sampling grid in two of three site-years while Order 2 zones were not correlated (Table 4). Topography and the 66-m grid were more highly correlated than the Order 1 survey in 1994 and 1995. Spatial variability was low at Gardner in 1996 compared with 1994 and 1995, as shown by the relatively low standard deviation and the high nugget value compared with sill, which suggests that much of the variation between values in 1996 was due to random error and not spatial relation-

Table 4. Correlation of NO_3–N estimates from sampling based on soil survey, topography, and 66-m grid sampling estimates compared with values from the originally sampled 33-m grids (or 45-m grids in the west two fields at Mandan).

Site	Year	Topography	66-m grid	Order 1	Order 2
		r			
Gardner	1994	0.24**	0.51**	0.03	0.00
	1995	0.26**	0.39**	0.18*	0.00
	1996	0.01	0.07	0.17*	0.00
Hunter	1997	0.22**	0.24**	0.01	0.06
	1998	0.09	0.10	0.21**	0.01
Colfax	1995	0.30**	0.62**	0.17*	0.04
	1996	0.39**	0.41**	0.16†	0.05
	1997	0.02	0.33**	0.26**	0.06
	1998	0.21**	0.10	0.06	0.08
Valley City	1994	0.29**	0.18	0.08	0.01
	1995	0.38**	0.50**	0.12	0.26**
	1996	0.49**	0.34**	0.24**	0.16†
	1997	0.09	0.22*	0.16†	0.02
	1998	0.23*	0.22*	0.08	0.09
Mandan	1995	0.83**	0.29**	0.19*	0.25**
	1996	0.29**	0.20*	0.37**	0.20**
	1997	0.83**	0.81**	0.54**	0.83**
	1998	0.46**	0.20*	0.38**	0.10

* $P < 0.05$.
** $P < 0.01$.
† $P < 0.10$.

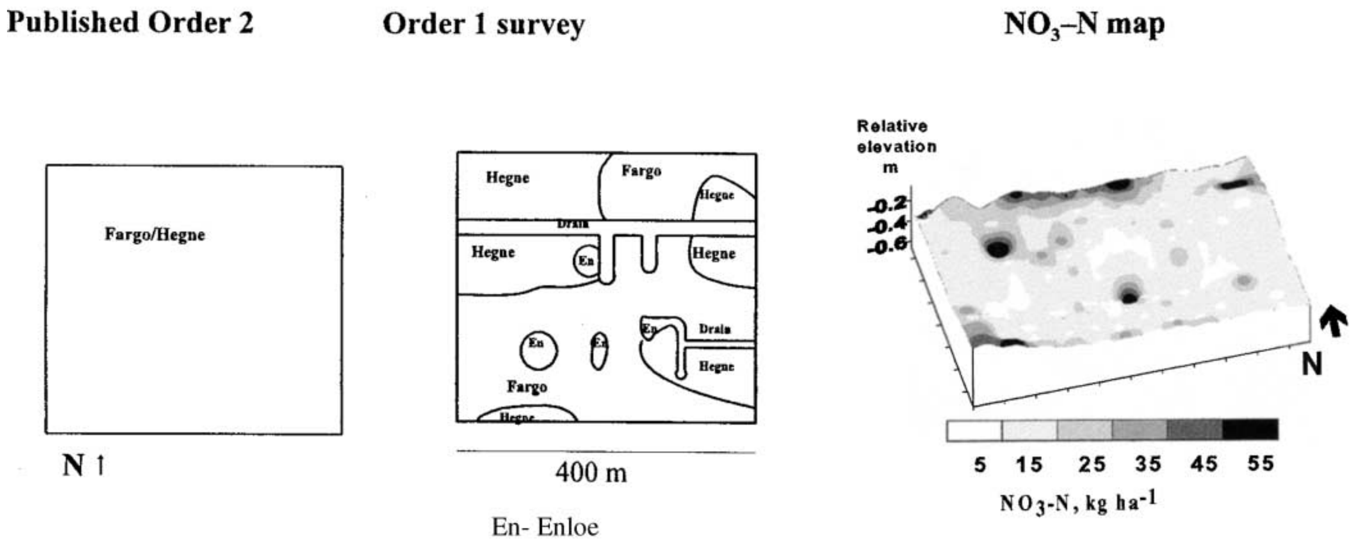


Fig. 2. Comparison of maps from an Order 1 survey and published Order 2 survey of the Gardner site, with a NO_3–N map from the 1995 sampling.

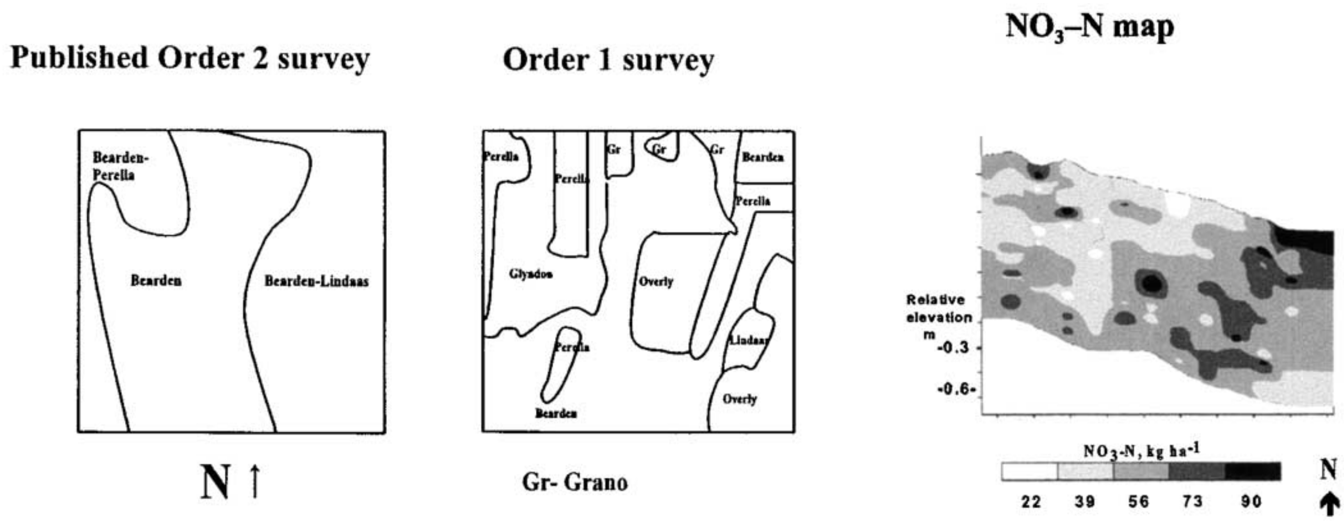


Fig. 3. Comparison of maps from an Order 1 survey and published Order 2 survey of the Hunter site, with a NO_3–N map from 1997.

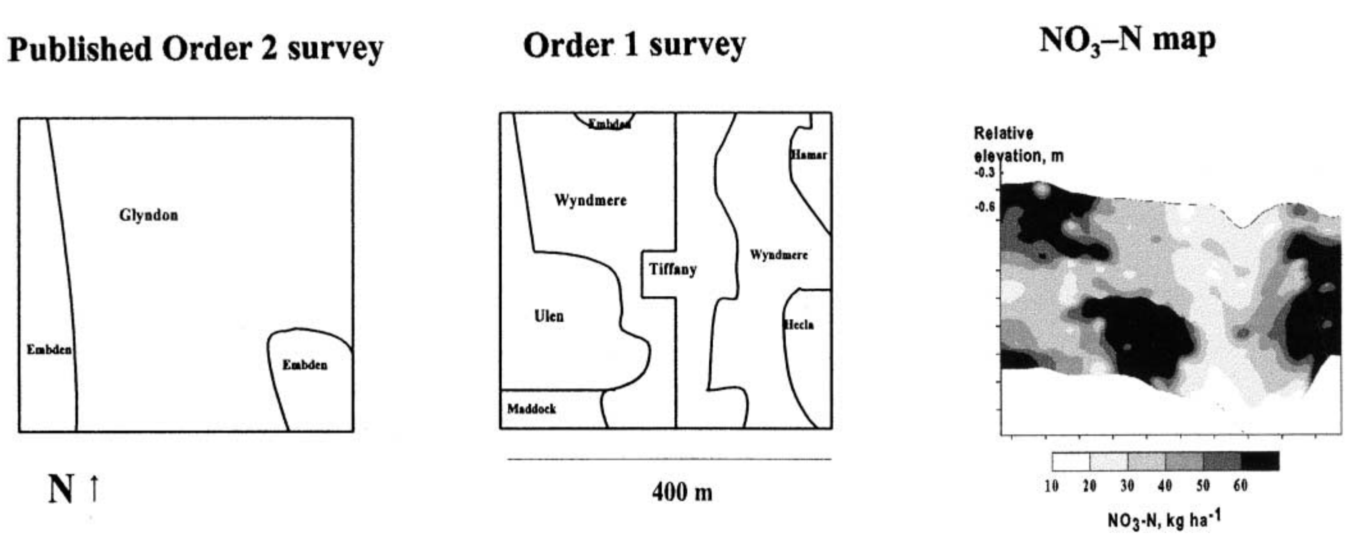


Fig. 4. Comparison of maps from an Order 1 survey and published Order 2 survey of the Colfax site, with a NO_3–N map from 1996.

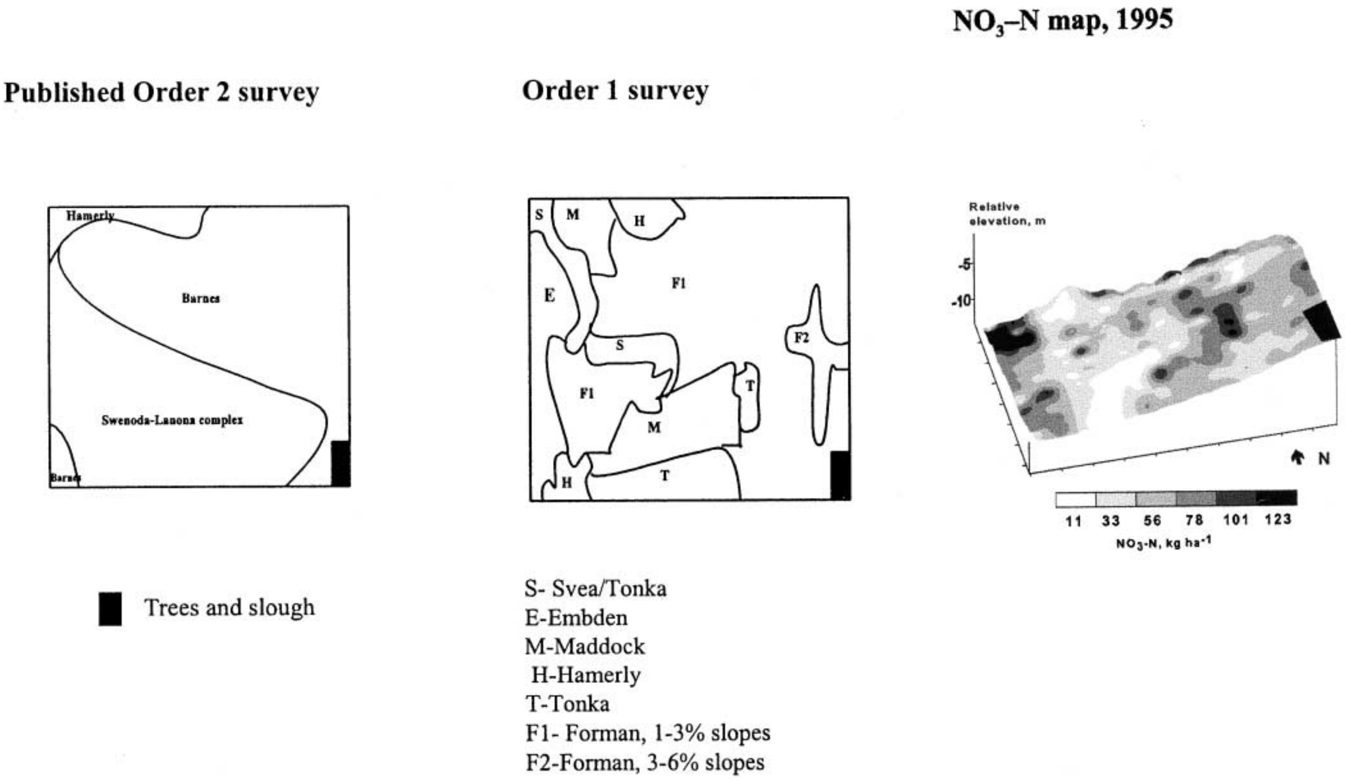


Fig. 5. Comparison of maps from an Order 1 survey and published Order 2 survey of the Valley City site, with a NO_3–N map from 1995.

ships. The low variation in soil NO_3–N levels was due to a cropping change from annual crops to alfalfa (Franzen et al., 1999a). Therefore, it is reasonable to expect that no sampling design would be related to field values, other than a composite sampling or mean sample value.

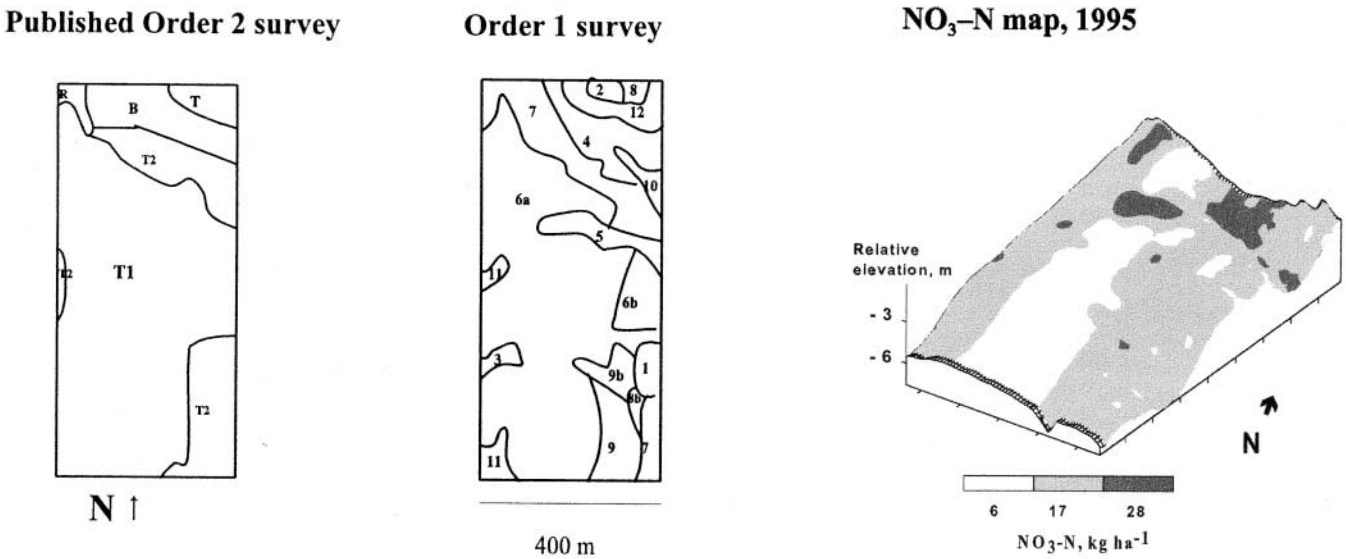
The Hunter Order 2 map in Fig. 3 (Prochnow et al., 1985) suggests some of the patterns that appear in the NO_3–N map, especially the greater N levels in the northwest delineated by the Bearden–Perella map unit. There is also a tendency towards greater N levels in the eastern side of the map, represented by the Bearden–Lindaas mapping unit. However, the Order 1 survey does a better job of delineating areas of higher N formed by the Bearden and Perella map units and a lower N level within the Glyndon mapping unit.

At Hunter, in 1997, the Order 1 or Order 2 NO_3–N estimates were not correlated with the 33-m grid values. However, both topography and 66-m grid sampling techniques were significantly correlated with the 33-m grid values. In 1998, there was low variability of soil NO_3–N values due to the sugarbeet crop, which tends to accumulate excess N in the foliage, leaving relatively low and uniform soil NO_3–N levels in the soil (Franzen et al., 1999b). The low variability in most of the field was not reflected in Table 2 because of poor sugarbeet growth along field edges (due to poor drainage from fence lines, hedges, and road ditches), resulting in high levels of residual N. Within the field, there was very low soil N variability in 1998 compared with 1997, which resulted in topography and the 66-m grid estimates not being correlated with the 33-m grid in 1998. However, the Order 1 survey was correlated in 1998, which was similar to the situation at Gardner where variability of NO_3–N was low.

At Colfax, the Order 2 survey (Fig. 4) (Thompson and Joos, 1975) suggests that there may be differences in elevation with the coarser-textured Embden soils in the western edge and southeast corner of the map. The Order 1 survey, however, provides a much closer representation of the lower N levels defined by the Tiffany soil and the higher N levels defined by the Wyndmere, Hecla, and Hamar soils. Order 2 survey estimates were not correlated with 33-m values. The Order 1 survey estimates were correlated in two of four site-years but were less correlated than either the topography zones or the 66-m grid.

The Order 2 survey of the Valley City site (Opdahl et al., 1990) revealed that there are differences between the western and eastern portions of the map. There is a different soil series in the northwest, which corresponds to higher N levels in the NO_3–N map. However, the Order 1 map helps to explain lower N levels in the Maddock soil and higher N levels in the Tonka and Forman soils. The Order 1, however, failed to delineate an important zone in the ridge of Forman soils in the northwest, which has a lower N level than the Forman soils to the west or east of the ridge top.

At Valley City, topography and the 66-m grid estimates were significantly correlated with 33-m NO_3–N values in four of five site-years. The Order 1 and Order 2 surveys were similarly correlated, with two of five site-years having significance. The performance of the Order 1 survey at this field is disappointing, given the success at identifying several areas especially in the western part



Legend

Order 2: T1, Temvik–Williams complex, 0–3% slopes
T2, Temvik–Williams complex, 3–6% slopes
B, Belfield–Grail complex, 0–2% slopes
R, Regent–Janesburg complex, 0–6% slopes

Order 1: 1, Belfield, 1–3% slopes
3, Farland, 0–1% slopes
5, Grassna, 0–1% slopes
7, Williams, 3–6% slopes
9, Williams–Wilton complex, 1–3% slopes
10, Williams–Wilton complex, 6–12% slopes
2, Daglum, 0–1% slopes
4, Grail–Arnegard complex, 0–1% slopes
6a, Temvik, 0–2% slopes; 6b, Temvik, 3–6% slopes
8, Williams, 6–9% slopes; 8b, Williams, 9–12% slopes
9b, Williams–Wilton complex, 3–6% slopes
11, Wilton, 0–2% slopes
12, Wilton, 3–6% slopes

Fig. 6. Comparison of maps from an Order 1 survey and published Order 2 survey of the Mandan site, with NO_3–N map from 1995.

of the field that fit zones defined in the topography zone and NO_3–N mapping. However, the lack of definition of the ridge top in the northeast part of the map as a separate soil-mapping unit from the rest of the Larson mapping unit deprived the estimates of at least two important zones defined in both the topography and NO_3–N mapping.

At Mandan, there were similar features in the northeast corner of both the Order 1 and Order 2 (USDA-NRCS, unpublished, 1998) maps (Fig. 6). The area defined as Belfield/Grail in the Order 2 is defined as a Grail/Arnegaard in the Order 1 map, but both represent areas of higher N levels shown in the NO_3–N map. Both survey maps also predict a lack of variability in N levels in the west and south areas of the field. The low strip of NO_3–N levels shown in the center of the map was following sunflower. Soil NO_3–N levels following sunflower were very low in all years of the study. The field west of the strip was in winter wheat, and the field in the east was spring wheat. The east field was consistently more variable than the center or west fields throughout the study years. In the center field, there is an area of higher N where the sunflower died due to excess water. This area was mapped using topography, but even the Order 1 survey missed this important location. The Order 1 mapping did note several small areas of Wilton and Farland soils in the west field, which tended to be higher in soil NO_3–N levels in some years of the study due to lower crop yields at these locations.

Estimates for the Order 2 soil survey zone were significantly correlated with 33- and 45-m grid NO_3–N levels in only 4 of 18 site-years. The Order 2 soil survey was most useful at Mandan where three of the four site-years were significantly correlated. The Order 1, topography, and 66-m grid sampling estimates were correlated with the 33- and 45-m grid sampling in all four site-years. The Order 2 survey was similar to the Order 1 survey in site-years of significance at Valley City. Both Order 1 and Order 2 surveys were less correlated than topography zones or a 66-m grid at all sites. Topography and the 66-m grid estimates were significantly correlated in 14 of 18 comparisons while the Order 1 surveys were significantly correlated in 11 of 18 site years.

While correlation of Order 1 and Order 2 soil surveys were significant in a number of comparisons, it should be clear from comparing NO_3–N levels with the soil survey mapping in Fig. 2 through 6 that basing a N management zone solely on the use of either survey may be a mistake. Certainly there are instances, such as at Colfax, where the Order 1 soil survey map closely resembles the nutrient map. However, at Gardner, the relationship is harder to see. Correlation gives us *footprints in the snow* that can be used to compare zone determination methods; however, when correlations are low, even if statistically significant, they would not be expected to delineate zone boundaries independent of other information.

The published Order 2 surveys were related to field nutrient levels in only a small number of the fields studied. Although an Order 2 survey is useful for introducing general soil properties to a region related to its scale, the use of a published county survey or digitized soil survey with an Order 2 scale may result in potentially serious errors if used for within-field N management. More useful information was obtained from the Order 1 soil surveys, and the patterns were more consistently related to soil NO_3–N levels. The Order 1 surveys were not as consistently correlated with 33- to 45-m grid sample values compared with estimates using topography or dense grid sampling (66-m grid spacing).

There were six site-years in which correlation was higher with the 66-m grid than with topography. This increase in correlation was probably due to sample number and the presence of within-zone variability. When zone nutrient values were high, variability within the zone was also high. This is consistent with other research conducted within these fields (Franzen and Berglund, 1998). However, there were six site-years in which the topographic approach was more highly correlated than the 66-m grid. Higher correlation with topography was found at Valley City and Mandan where nutrient levels were relatively low and greater variation in elevation within the topography was present. The advantage of topographic sampling over the 66-m grid sampling is that the approach correlated significantly with the 33-m grid values using only five to seven samples in a 12.5-ha field as opposed to 36 samples in the 66-m grid. It is not economically practical to sample fields for NO_3–N in a 66-m grid. The topographic approach is less expensive, less time consuming, and can be practically conducted.

The Order 1 survey-based sampling was not as highly correlated as the 66-m grid in 12 site-years and was more highly correlated than the 66-m grid in four site-years. Although the Order 1 surveys were much more related to NO_3–N patterns than the Order 2 surveys, they probably should be compared with other forms of information, such as three-dimensional topography maps, aerial photography of bare soil and crops, satellite images of crops, soil electrical conductivity (EC) detectors, yield maps, or grain protein monitors, to verify that the patterns observed show consistency between data sets. Use of an Order 1 survey should therefore be a supplement to other types of spatial data rather than a stand-alone source for determining management zone.

SUMMARY

Use of an Order 2 soil survey, such as appears in most county soil survey publications, was seldom useful in determining zones for within-field management of NO_3–N. The Order 1 soil survey was much more related to soil NO_3–N levels than the Order 2 surveys, but its consistency was not as high as when topography-based zones or a 66-m (approximately 2.5 samples per hectare) grid was used. The Order 1 soil survey would be a useful information layer to help determine or verify site-specific nutrient management zones or soil sampling zones to reduce sampling costs compared with a dense grid sampling. However, it should not be the only layer of information to determine these zones. Because of water movement patterns within soil landscapes, more work should be conducted to determine which series would tend to accumulate or redistribute nutrients on landscapes. This would foster the proper separation of soil series, types, and phases for within field site-specific management. Site-specific agriculture is putting fresh demands on soil survey. An Order 1 survey would be far more expensive than the present Order 2 scale. Given its positive role in contributing to determination of N management zones, the private and public sector will need to determine whether it is worth the cost.

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REFERENCES

Atherton, B.C., M.T. Morgan, S.A. Shearer, T.S. Stombaugh, and A.D. Ward. 1999. Site-specific farming: A perspective on information needs, benefits and limitations. J. Soil Water Conserv. 51:66–71.

Carr, P.M., G.R. Carlson, J.S. Jacobsen, G.A. Nielsen, and E.O. Skogley. 1991. Farming soils, not fields: A strategy for increasing fertilizer profitability. J. Prod. Agric. 4:57–61.

Clay, D.E., C.G. Carlson, F. Brix-Davis, J. Oolman, and B. Berg. 1997. Soil sampling strategies for estimating residual nitrogen. J. Prod. Agric. 10:446–452.

Dahnke, W.C., and R.A. Olson. 1990. Soil test correlation, calibration, and recommendation. p. 45–71. *In* R.L. Westerman (ed.) Soil testing and plant analysis. SSSA Book Ser. 3. SSSA, Madison, WI.

Ferguson, R.B., C.A. Gotway, G.W. Hergert, and T.A. Peterson. 1996. Soil sampling for site-specific nitrogen management. p. 13–22. *In* P.C. Robert et al. (ed.) Precision agriculture. Proc. Int. Conf., 3rd, Minneapolis, MN. 23–26 June 1996. ASA, CSSA, and SSSA, Madison, WI.

Franzen, D.W., and D. Berglund. 1998. Small-scale spatial variability of soil N and P and implications with regard to sample core number. p. 143–153. *In* 1997 sugarbeet research and extension reports. North Dakota State Univ. Ext. Serv. and Minnesota–North Dakota Sugarbeet Res. and Educ. Board, Fargo, ND.

Franzen, D.W., L.J. Cihacek, V.L. Hofman, and L.J. Swenson. 1998. Topography-based sampling compared with grid sampling in the northern Great Plains. J. Prod. Agric. 11:364–370.

Franzen, D.W., V.L. Hofman, L.J. Cihacek, and L.J. Swenson. 1999a. Soil nutrient relationships with topography as influenced by crop. Precis. Agric. 1:167–183.

Franzen, D.W., and T.R. Peck. 1995. Field soil sampling density for variable rate fertilization. J. Prod. Agric. 8:568–574.

Franzen, D.W., and T.R. Peck. 1996. Grid sampling or topography sampling for soil nutrients. p. 41–49. *In* P. Scharf (ed.) Proc. North Central Ext. Industry Soil Fertil. Conf., St. Louis, MO. 20–21 Nov. 1996. Potash and Phosphate Inst., Brookings, SD.

Franzen, D.W., L. Reitmeier, J.F. Giles, and A.C. Cattanach. 1999b. Aerial photography and satellite imagery to detect deep soil N levels in potato and sugarbeet. p. 281–290. *In* P.C. Robert et al.

(ed.) Precision agriculture. Proc. Int. Conf., 4th, St. Paul, MN. 19–22 July 1998. ASA, CSSA, and SSSA, Madison, WI.
Gotway, C.A., R.B. Ferguson, and G.W. Hergert. 1996. The effects of mapping and scale on variable-rate fertilizer recommendations for corn. p. 321–330. *In* P.C. Roberts et al. (ed.) Precision agriculture. Proc. Int. Conf., 3rd, Minneapolis, MN. 23–26 June 1996. ASA, CSSA, and SSSA, Madison, WI.
Hergert, G.W., W.L. Pan, D.R. Huggins, J.H. Grove, and T.R. Peck. 1997. Adequacy of current fertilizer recommendations for site-specific management. p. 283–300. *In* F.J. Pierce and E.J. Sadler (ed.) The state of site-specific management for agriculture. ASA, CSSA, and SSSA, Madison, WI.
Jenny, H. 1941. Factors of soil formation. McGraw-Hill Book Co., New York.
Kellogg, C.E. 1961. Soil interpretation in the soil survey. In-service publication. USDA-SCS, Washington, DC.
Lamb, J.A., G.A. Rehm, and G.L. Malzer. 1995. What grid cell size is best for P and K soil testing in Minnesota? p. 1–10. *In* G. Rehm (ed.) Proc. North Central Ext. Industry Soil Fertil. Conf., St. Louis, MO. 15–16 Nov. 1995. Phosphate and Potash Inst., Brookings, SD.
Mausbach, M.J., D.J. Lytle, and L.D. Spivey. 1993. Application of soil survey information to soil specific farming. p. 57–68. *In* P.C. Robert et al. (ed.) Soil specific crop management. Proc. Workshop, Minneapolis, MN. 14–16 Apr. 1992. ASA, CSSA, and SSSA, Madison, WI.
Nordt, L.C., J.S. Jacob, and L.P. Wilding. 1991. Quantifying map unit composition for quality control in soil survey. p. 183–197. *In* M.J. Mausbach and L.P. Wilding (ed.) Spatial variabilities of soils and landforms. SSSA Spec. Publ. 28. SSSA, Madison, WI.
Opdahl, D.D., W.J. Terry, and N.D. Prochnow. 1990. Soil Survey of Barnes County, North Dakota. USDA-SCS. U.S. Gov. Print. Office, Washington, DC.
Peck, T.R., and P.N. Soltanpour. 1990. The principles of soil testing. p. 1–9. *In* R.L. Westerman (ed.) Soil testing and plant analysis. SSSA Book Ser. 3. SSSA, Madison, WI.
Pierce, F.J., and P. Nowak. 1999. Aspects of precision agriculture. Adv. Agron. 67:1–85.
Prochnow, N.D., N.J. Lunde, W.J. Terry, and D.P. Opdahl. 1985. Soil Survey of Cass County Area North Dakota. USDA-SCS. U.S. Gov. Print. Office, Washington, DC.
Sawyer, J.E. 1994. Concepts of variable rate technology with considerations for fertilizer application. J. Prod. Agric. 7:195–201.
Soil Survey Division Staff. 1993. Soil survey manual. USDA Handb. 18. USDA, Washington, DC.
Steinwand, A.L., D.L. Karlen, and T.E. Fenton. 1996. An evaluation of soil survey crop yield interpretations for two central Iowa farms. J. Soil Water Conserv. 51:66–71.
Thompson, D.G., and L. Joos. 1975. Soil Survey of Richland County and Cheyenne National Grassland Area of Ransom County, North Dakota. USDA-SCS. U.S. Gov. Print. Office, Washington, DC.
Vendrell, P.F., and J. Zupancic. 1990. Determination of soil nitrate by transnitration of salicylic acid. Commun. Soil Sci. Plant Anal. 21:1705–1713.
Westfall, D.G., R.A. Ortega, and G.A. Peterson. 1998. Landscape variability and wheat management. p 1–9. *In* Proc. Intensive Wheat Manage. Conf., Denver, CO. 4–5 Mar. 1998. Potash and Phosphate Inst., Brookings, SD.
Wollenhaupt, N.C., R.P. Wolkowski, and M.K. Clayton. 1994. Mapping soil test phosphorus and potassium for variable-rate fertilizer application. J. Prod. Agric. 7:441–448.

ERRATA

Germination and Seedling Cold Tolerance in Sorghum: I. Evaluation of Rapid Screening Methods

Iskender Tiryaki and David J. Andrews; Agron. J. 93:1386–1391 (2001).

We wish to report two errors that occurred on page 1386 of the above paper, which appeared in the November–December 2001 issue.

In the author–paper documentation footnote, “Kahramanmaras Suteu Imam Univ.” should read “Kahramanmaras Sutcu Imam Univ.” instead. Also, the corresponding author’s email address should appear as “tiryaki@unlserve.unl.edu,” not “tiryaki@nlserve.unl.edu.”

Germination and Seedling Cold Tolerance in Sorghum: II. Parental Lines and Hybrids

Iskender Tiryaki and David J. Andrews; Agron. J. 93:1391–1397 (2001).

In this companion paper appearing in the same issue, “Kahramanmaras Suteu Imam Univ.” was also misspelled in the author–paper documentation footnote on page 1391. It should read “Kahramanmaras Sutcu Imam Univ.” instead. We apologize for any confusion.